CDF Note 7286

Search for New Particles Decaying to High Mass Dielectrons or Dimuons at CDF II

The CDF Collaboration

URL http://www-cdf.fnal.gov

(Dated: November 19, 2004)

We report on results for searches for a new particle (X) in dielectron and dimuon (dilepton, ll) decay modes using approximately 200 pb^{-1} of p$\bar{\text{p}}$ collision data at $\sqrt{s} = 1.96$ TeV collected by the CDF II experiment at the Tevatron. We present limits on $\sigma(\bar{p}p \to X \to ll)$ as a function of M_{ll}, where we consider X categorized with respect to its spin (0, 1, or 2). We set lower mass bounds at 95% C.L. for a sneutrino (725 GeV/c^2), additional neutral gauge bosons $Z'_{\rm SM}$, Z_ψ, Z_η, Z_χ, Z_I, little Higgs Z_H (815, 690, 715, 670, 875 GeV/c^2), techni-mesons $\omega_{\rm T}$ and $\rho_{\rm T}$ (320 GeV/c^2), and the Randall-Sundrum extra dimension graviton (700 GeV/c^2).

Preliminary Results

I. INTRODUCTION

We present results from a search for new particles (X) in the prompt dilepton (ee and $\mu\mu$) decay channel in $p\bar{p}$ collisions ($p\bar{p} \to X \to ll$) at $\sqrt{s} = 1.96$ TeV with the CDF detector at the Fermilab Tevatron. We search for X directly by comparing the observed dilepton invariant mass (M_{ll}) distribution above > 150 GeV/c^2 to the expected background invariant mass distribution. We search for numerous new particles predicted in models beyond the Standard Model (SM). Many of these models predict particles with masses at the TeV/c^2 scale [1]. To discover or to constrain a new model (to set mass bounds for a particle, for example), the experimental sensitivity for the particle, which depends on the nature of the particle, needs to be known. The geometrical acceptance, which affects the overall sensitivity, depends on the spin of X, since the spin determines the angular distribution of the decayed dileptons. To make our results as model independent as possible, we search for generic spin 0, 1 and 2 particles with certain widths. This approach allows us to search for large classes of new particles. Examples of such particles presented here are: R-parity violating sneutrinos ($\widetilde{\nu}$) (spin 0); additional heavy neutral gauge bosons ($Z'_{\rm SM}$, Z_ψ, Z_η, Z_χ, Z_I, Z_{LH}) and technicolor particles (spin 1); the first excitation of the graviton in the Randall-Sundrum model (spin 2). We obtain a $\sigma(X_{ll})$ limit (95% confidence level upper limit on $p\bar{p} \to X \to ll$ as a function of M_{ll}) for each spin value. The $\sigma(X_{ll})$ limit can be used to determine lower mass bounds for X. The discovery of any of these particles could potentially transform the field of particle physics. New experimental bounds on these models are also essential to the progress of the particle physics phenomenology.

Here, we briefly describe the particles mentioned above and the parameters relevant for the production and decay of these particles, to be used for the mass bounds. R-parity violating SUSY model predicts a superpartner of neutrino ($\widetilde{\nu}$) [2] with spin and charge of zero. The $\widetilde{\nu}$ can be produced in $d\bar{d}$ annihilation (coupling strength given by λ') and can have non-zero branching fraction (Br) to high mass dileptons. Additional neutral gauge bosons (Z') are expected in many models in the extension of the SM in an existence of the higher gauge structure. We explore four different E_6 Z' bosons for four different values of the mixing angle, $\cos\theta$, of the higher neutral gauge boson structure. We follow the convention of [3] for the definitions of the four Z': Z_ψ, Z_η, Z_χ, Z_I. The SM-like Z' boson ($Z'_{\rm SM}$) is a reference model which has the same coupling strengths to quarks and leptons as those of the SM Z^0 boson. The littlest Higgs model predicts the existence of new gauge bosons along with other additional particles at the TeV scale. The neutral $SU(2)$ vector boson, Z_H of the little Higgs model can be observed at hadron colliders via the Drell-Yan process. The mixing angle of the gauge bosons, $\cot\theta$, is the parameter that is relevant for the production and decay of Z_H. The formalism used for the couplings is as in [4, 5]. Technicolor, an alternative way to manifest the Higgs mechanism, predicts spin-1 techni-mesons, ω_{T} and ρ_{T}, which are narrow resonances. The Straw-man's technicolor model (TCSM) ([6]) is used to describe the phenomenology of ω_{T} and ρ_{T}. The choice on the Techni-scale parameter, M_T, affects both the production cross section of the vector mesons and the rate $\omega_{\mathrm{T}} \to \gamma + \pi_{\mathrm{T}}$. A warped extra dimension model (Randall-Sundrum, RS) [7] predicts graviton resonances that can be produced at the Tevatron. The properties of the RS graviton states may be expressed in terms of a dimensionless coupling parameter, $\mathrm{k/M_{Pl}}$ the relative strength of the warped dimension's curvature scale, k, to the effective Planck scale.

II. DATA SAMPLE & EVENT SELECTION

The analysis uses an integrated luminosity of 200 pb^{-1} collected with the CDF II detector [8] between March 2002 and September 2003. The data are collected with an inclusive lepton trigger that requires an electron ($\mathrm{E}_T > 18$ GeV) or muon ($p_{\mathrm{T}} > 18$ GeV/c). The $E_{\mathrm{T}} > 70$ GeV electron trigger which has looser requirements is also used to maintain high efficiency at high transverse energy (E_{T}). From this inclusive lepton dataset, events are selected offline with two reconstructed isolated electrons or muons E_T (muon p_{T}) greater than 25 GeV/c (20 GeV/c). The leptons are required to satisfy high E_T identification criteria.

Dielectron candidate events are selected by the combinations of central EM (CEM) and Plug EM (PEM) electrons: CC (CEM tight, CEM loose) or CP (CEM tight, PEM loose). Dimuon candidate events are selected by requiring one muon to be detected in the central region covered by the muon trigger ($|\eta| < 1.0$) and the other one should at least have a reconstructed track in the Central Outer Tracker (COT) (up to $|\eta| \lesssim 1.5$). The efficiencies of the lepton identification cuts are determined using a nearly pure sample of dilepton events from Z^0 decays by requiring invariant mass to be between 70 and 110 GeV/c^2 for dielectrons and 80 and 100 GeV/c^2 for dimuons. The overall dilepton identification efficiencies are $(92 \pm 3)\%$, $(80 \pm 5)\%$ and $(70 \pm 2)\%$ for CC, CP dielectrons and dimuons, respectively. The geometrical and kinematic acceptance for dilepton events as a function of signal mass, for three different spins, is determined by Monte Carlo simulation using Pythia event generator [9] with CTEQ5L parton distribution functions [10]. The total dilepton efficiencies combining selection efficiencies and acceptance for detecting $X \to ee$ and $X \to \mu\mu$ events are similar and $\approx 50\%$ for $M_X > 400$ GeV/c^2, for all spins considered. The acceptances are dominated by events falling in the central detector at high mass.

TABLE I: Expected number of background events compared with data.

	ee		$\mu\mu$	
Mass GeV/c^2	observed events	expected background	observed events	expected background
M > 150	184	193.5 ± 99.2	58	55.3 ± 2.5
M > 200	70	68.1 ± 33.3	18	20.9 ± 1.0
M > 300	14	10.7 ± 4.3	6	5.2 ± 0.3
M > 400	3	2.1 ± 0.7	1	2.3 ± 0.2
M > 500	0	0.5 ± 0.1	1	1.2 ± 0.1

III. BACKGROUNDS

The major background contribution is from dilepton events from the Drell-Yan production (which includes $\gamma*$ continuum and the Z boson). The contributions from other processes which produce dilepton final states, such as $t\bar{t}$, $\tau^+\tau^-$, W^+W^-, and W^+Z^- are considered and found to be much smaller than Drell-Yan (non-DY prompt background). Nevertheless, they are included in the background estimates for both ee and $\mu\mu$ channels. The acceptances for the prompt backgrounds are estimated using simulation. All events, except $t\bar{t}$ which uses Herwig event generator [11], have been generated by Pythia. The lepton identification cuts are optimized for high efficiency. As a result, some of the accepted ee events are from non-dielectron sources, predominantly from misidentified QCD dijet events. This background is estimated from the sideband regions for the two electron isolation vs isolation distribution, extrapolating QCD expectations in the signal region. The dominant background to the dimuon data from the non-beam collisions is from cosmic rays. This background is estimated from a sample of cosmic ray events which pass the signal selection criteria. Figure 1 shows the invariant mass distributions of ee and $\mu\mu$ data and the estimated background. In Table I, we compare integrated number of events above given M_X for the data observed, background estimated, and signal expected. No significant excess of events is observed.

IV. LIMIT SETTING METHOD

The $\sigma(X_{ll})$ limit are extracted by comparing the observed dilepton invariant mass distribution to a superposition of the expected background distributions shown in Fig. 1 and expected signals using a Bayesian binned likelihood method. For the combined dilepton results, a joint likelihood is formed from the product of the individual channel likelihoods, taking into account the uncertainties as discussed in the section below. The resulting joint likelihood is converted to a posterior density in the signal cross section. The 95% C.L. upper limits in $\sigma(X_{ll})$ limit are obtained by integrating this posterior density numerically. The process is repeated for signals with spin 0, 1 and 2 for a number of masses ranging up to 900 GeV/c^2. The 95% C.L. mass lower limits are obtained using the intersection of the $\sigma(X_{ll})$ limit experimental upper limit curves and the theoretical production curves for the particles listed in Section I.

A. Systematic Uncertainties

The systematic uncertainties considered in the analysis are from similar sources in both ee and $\mu\mu$ channels. These are the uncertainties from the choice of PDF, energy (momentum) scale and resolution for the acceptance and efficiency, luminosity and background shape and normalization errors. The overall signal uncertainty for both channels is 8%. The background uncertainty due to misidentified jets in the electron channel is about 50%. For the dimuons, the contribution is found to be 30%. The uncertainties for prompt dimuon final states are estimated to be 5% and the cosmic ray background uncertainty is estimated to be about 20%. For the combined dilepton results, PDF choice, luminosity and common selection efficiency (the event vertex selection efficiency) uncertainties are considered correlated.

V. RESULTS

We have performed a search for additional neutral heavy bosons, in the ee and $\mu\mu$ decay modes, using a data sample of 200 pb^{-1} collected with the CDF II detector collected between spring 2002 and fall 2003. The observed dilepton invariant mass spectra are consistent with the background expectations. We combine the ee and $\mu\mu$ channels to set preliminary combined dilepton cross section upper limits at 95% C.L. in the high mass region. We also place preliminary lower bounds on particles in different spin categories:

- Spin-0: RPV $\widetilde{\nu}_\tau$,
- Spin-1: Sequential Z$'$, E$_6$ Z$'$s, Little Higgs Z$'$ and Technicolor $\omega_{\rm T}$ and $\rho_{\rm T}$,
- Spin-2: Randall-Sundrum graviton of the first excited state.

The $\sigma(X_{ll})$ limit upper limit results for spin-1, spin-2 and spin-0 in dilepton combined channels are shown in Figures 2, 3 and 4. The lower mass bounds for the models listed above are given in Tables II–VI, for various values of each model's parameters. Table VII summarizes the chronology of the CDF searches for SM-like Z′ in dilepton decay mode [12], [13].

Acknowledgments

We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. This work was supported by the U.S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Education, Culture, Sports, Science and Technology of Japan; the Natural Sciences and Engineering Research Council of Canada; the National Science Council of the Republic of China; the Swiss National Science Foundation; the A.P. Sloan Foundation; the Bundesministerium fuer Bildung und Forschung, Germany; the Korean Science and Engineering Foundation and the Korean Research Foundation; the Particle Physics and Astronomy Research Council and the Royal Society, UK; the Russian Foundation for Basic Research; the Comision Interministerial de Ciencia y Tecnologia, Spain; and in part by the European Community's Human Potential Programme under contract HPRN-CT-20002, Probe for New Physics.

---

[1] M. Cvetic, D.A. Demir, J.R. Espinosa, L. Everett, and P. Langacker, UPR-0737-T, Mar 1997.

[2] D.Choudhury, S.Majhi and V.Ravindran, Nucl. Phys. B **660**, 343 (2003).

[3] F. del Aguila, M. Quiros and F. Zwirner, Nucl. Phys. B **287**, 457 (1987).

[4] T. Han, H.E. Logan, B. McElrath and L. Wang, Phys. Rev. D **67**, 095004 (2003).

[5] Heather Logan, Phenomenology Institute, University of Wisconsin, private communication.

[6] K. D. Lane and S. Mrenna, Phys. Rev. D, **67**, 115011 (1999).

[7] L. Randall and R. Sundrum, Phys. Rev. Lett. **83**, 3370 (1999).

[8] The CDF II Detector Technical Design Report, Fermilab-Pub-96/390-E, 1996.

[9] T. Sjöstrand, P. Edén, C. Friberg, L. Lönnblad, G. Miu, S. Mrenna and E. Norrbin, Computer Phys. Commun., **135**, 238 (2001).

[10] H.L.Lai *et al.*, e-Print Archive: hep-ph/9903282, (1999).

[11] G. Corcella et al., JHEP **01**, 10 (2001).

[12] F. Abe *et al*, the CDF Collaboration, Phys. Rev. Lett. 68, 1463, 1992.

[13] F. Abe *et al*, the CDF Collaboration, Phys. Rev. Lett. 79, 2191, 1997.

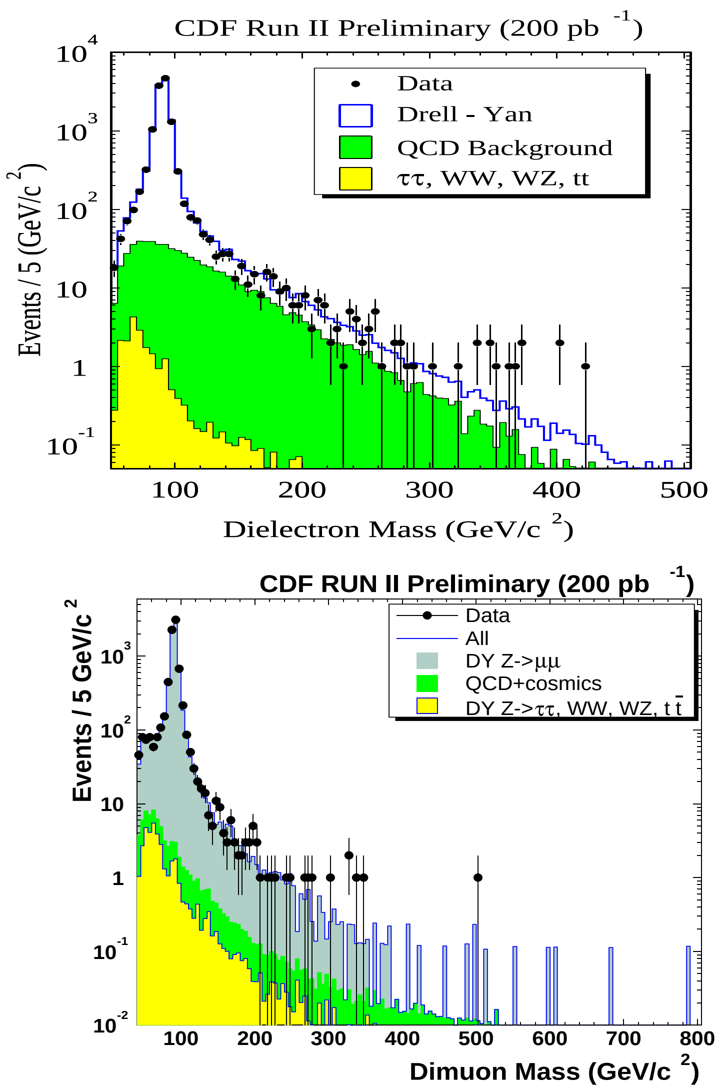

FIG. 1: Data (points) compared with the total background prediction (solid line) in ee (top) and $\mu\mu$ (bottom) invariant mass distribution.

TABLE II: Dilepton Results for E_6 Z's.

E$_6$ Mass Limit at 95%C.L (GeV/c^2)			
Model	ee	$\mu\mu$	$\ell^+\ell^-$
Z'_{SM}	750	735	815
Z'_{ψ}	635	600	690
Z'_{χ}	620	585	670
Z'_{η}	655	640	715
Z'_{I}	575	540	610

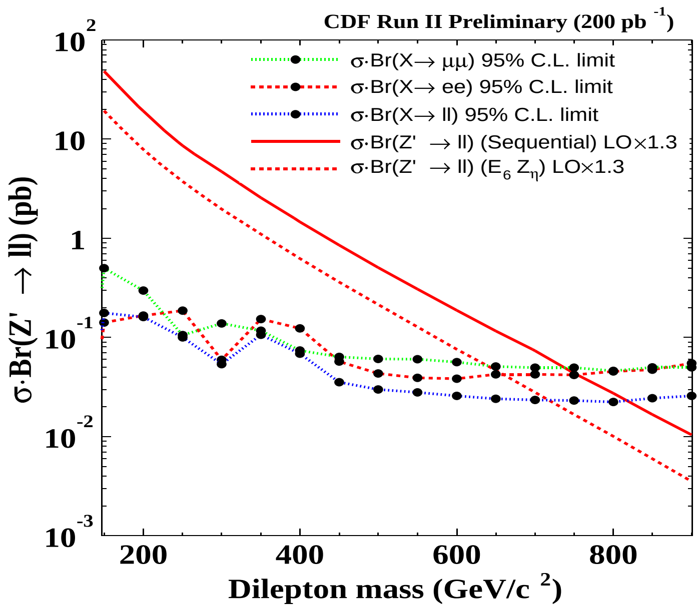

FIG. 2: 95% C.L. upper limit on σ . BR($Z'\to\ell^+\ell^-$) and a 95% C.L. lower limit on Z' mass for the sequential and E6 models.

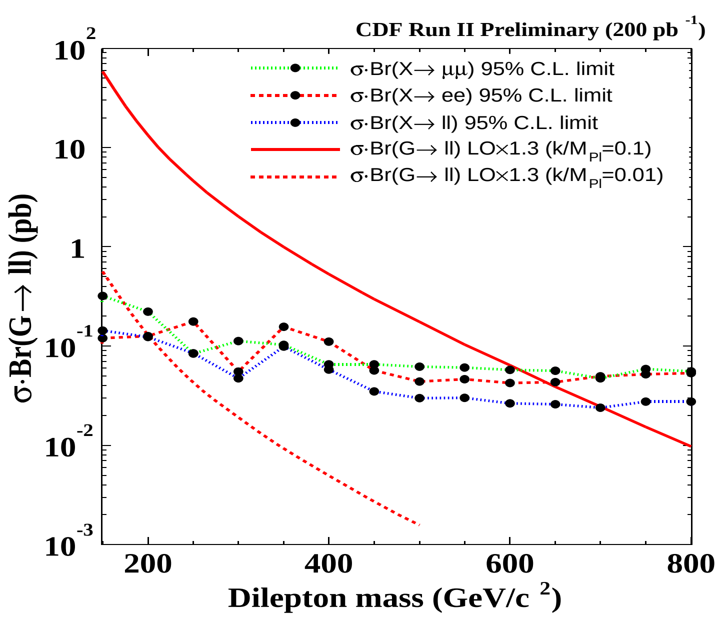

FIG. 3: 95% C.L. upper limit on σ . BR(G $\to\ell^+\ell^-$).

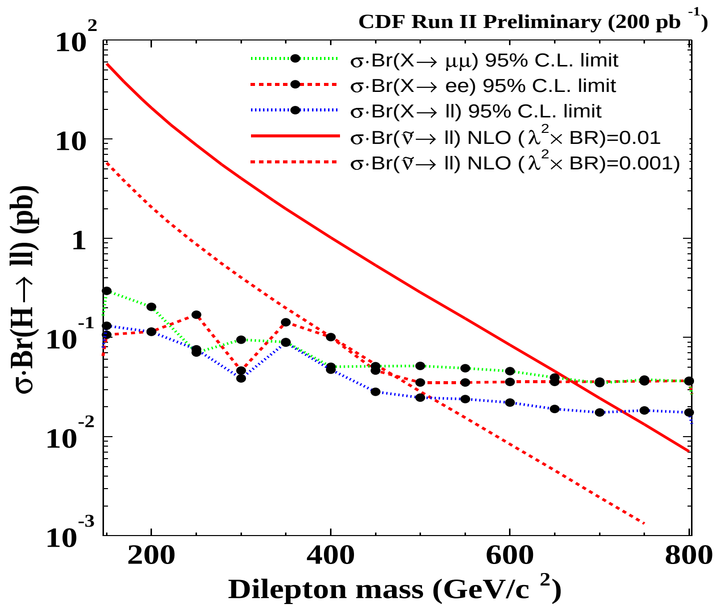

FIG. 4: 95% C.L. upper limit on σ . BR($\tilde{\nu}\rightarrow\ell^+\ell^-$).

TABLE III: Dilepton Results for Littlest Higgs Z$'$.

Z_H Mass Limit at 95%C.L (GeV/c^2)			
$\cot\theta$	ee	$\mu\mu$	$\ell^+\ell^-$
1.0	810	805	875
0.9	785	780	850
0.7	735	715	800
0.6	700	685	765
0.5	665	640	720

TABLE IV: Dilepton Results for Techni-mesons, ρ_T, ω_T.

TC Mass Limit at 95%C.L (GeV/c^2)	
M_T	$\ell^+\ell^-$
500	320
400	315
300	310
200	225

TABLE V: Dilepton Results for RS Graviton.

RS Graviton Mass Limit at 95%C.L (GeV/c^2)			
k/M_{Pl}	ee	$\mu\mu$	$\ell^+\ell^-$
0.1	640	610	700
0.05	485	455	525
0.01	200	170	200

TABLE VI: Dilepton Results for RPV $\widetilde{\nu}$.

$\widetilde{\nu}_\tau$ Mass Limit at 95%C.L (GeV/c^2)			
λ'^2·Br	ee	$\mu\mu$	$\ell^+\ell^-$
0.01	670	665	725
0.005	615	590	665
0.001	470	455	510

TABLE VII: History of CDF neutral spin-1 gauge boson searches in ee and $\mu\mu$ channels.

CDF Run II Preliminary

CDF Run	Luminosity (pb^{-1})		$M_{Z',95\%C.L}$ (GeV/c)		
	electron	muon	electron	muon	combined
Run I(A+B) ('92-'95)	109.7	107.4	650	590	690
Run IIA (summer '02)	10.4	16	460	275	—
Run IIA (winter '03)	72	72	650	455	665
Run IIA (summer '03)	126	126	720	585	730
Run IIA	200	200	750	735	815